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Shifting the Project Management Paradigm for Exploration
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I thought I might define project management by humorous example. It seems there was a customer in a pet shop who was interested in acquiring a parrot. And, so the shopkeeper pointed to three kind of similar looking parrots that were situated on a perch together. They were basically identical, and he inquired about the price of the parrots. And, the shopkeeper said, “Well, the parrot on the left cost $500.” And, he thought that was a remarkable price for a parrot, and asked about why. And, the shopkeeper said, “Well, that parrot on the left has great computer skills. So, he knows how to run a computer.” And, he inquired about the second parrot, and was told that the second parrot was a thousand dollars, because, not only did he possess all the skills that the first parrot had, but he could also do math and physics. And, when he inquired about the third – of course, he’s increasingly concerned about these prices, he inquired about the third parrot, he discovered the third parrot was priced at two thousand dollars. And, when he asked the shopkeeper why, what special skills does this third parrot posses, the shopkeeper said, “Well, to be honest with you, I’ve never seen him do anything. But, the other parrots tend to defer to him, and they call him the ‘project manager’.” (laughter) So, that’s what project management is about.

There are some sources for this talk. The administrator actually advised us to read a couple of books recently – which I did, and they got me to thinking about some things I think are important for where we are in our space program history right now. There’s an excellent book out there in our NASA history series by Howard McCurdy, called “Faster, Better, Cheaper”. Also, “The Secret of Apollo” by Stephen B. Johnson. This is really, almost mis-titled; “Secret of Apollo” is about the evolution of systems management in this country, and how it led to success in Apollo and other things. Really fascinating read, and I am going to speak about both of these things today because they’re the most important management paradigms that have been used in NASA over the years, in my opinion.

Also, there’s an interesting paper that was done by the Aerospace Corporation. It took a look at a complexity-based risk assessment for low-cost, well for faster, better, cheaper type missions – not just within NASA, but also in DARPA and other parts of DoD. What came out of that is something called the “Bearden Rule”, which I’ll talk about later. It’s an utterly fascinating look at the successes and risks around faster, better, cheaper.

So, what’s the motivation behind this talk? We’re in the business of building and integrating, and operating complex systems that have relatively high risk of failure. And, I mean relatively high compared to the other mundane things that go on in life. And, the consequences of failure are extraordinarily high. I don’t need to tell anybody in this room that, but that’s just the nature of our business. In the worse case scenario, the failures can lead to loss of life, loss of high-value systems and equipment, loss of national leadership and prestige – and Gerstenmaier was just talking about this a minute ago--our leadership in space, and how important it is to the nation. It can lead to loss of business, and it can lead to the loss of the mission itself. Mike Griffin commented on the fact yesterday, that he thought the job of systems engineering was to prevent unintended consequences in the interaction among subsystems, and I really believe that.

The reason that most of us, I think, are willing to undertake spaceflight, despite this amount of risk, also relates back to something Gerst just talked about, and that is our love for the mission is the reason that we do it. We do this mission because we believe in it, we do it because we think it's important. When the president brought out the vision for space exploration, he talked about its importance relative to economic and national security, and also with regard to scientific leadership. And, all those things resonate with me. Those are some of the important, sort of strategic and national reasons that we do it. But, he also said that the reason we do exploration is because it's a desire written in the human heart. And, I think it's important to recognize that there's an emotional component to it as well, in addition to the strategic one. So, if you look at it from any angle, the stakes in what we do are extremely high – an extremely high risk venture that's extremely important for a lot of national strategic, emotional reasons. Consequences for failure are high, so it's important for us to understand our systems management models, be able to adapt those in such a way that we can minimize the amount of risk that we undertake when we do systems work.

This is a photograph of the Gravity Probe B spacecraft. It actually has nothing to do with this discussion, but I was involved with the mission, and I like that picture, so that's the reason that it's in there. (laughter)

So, as I was discussing, basically the job of systems management is to manage risk. And, we've involved various management schemes over the years in order to do that. And, as I said, really sort of a thesis of this talk, is that you can look at systems management as a model, you could look at faster, better, cheaper as a model. And, I want to examine those a little bit historically, look at their chief characteristics, and see if there's something that we can do to draw from the best examples of both of those models.

Now, there are other things you can look at. There were models around concurrency that were used in the ballistic missile program in the '50s, that actually didn't turn out all that well. There are other ways of organizing and thinking about systems management, but I wanted to talk about the two dominant ones in NASA.

I did actually think about addressing Skunkworks, and my abstract even says that, but in the end I chose not to talk about that because I think it has more bearing in DoD than it does in NASA.

So, we're embarking in a new era of exploration, as I said. And, what's interesting about this, what's different about this, is I think it requires us to build systems that are unprecedented in terms of their scale and complexity. So, that should bear in our thinking on how we do systems management, as well.

There's an interesting undercurrent to this entire discussion, and, that is, there's a group of people out there that believe that large complex systems are just doomed to failure because of their complexity. There's a fairly famous book by a guy named Charles Perrow, called "Normal Accidents". And, he talks about this, and what he says is that basically large, complex systems are going to fail. The reason they're going to fail is because subsystems interact with one another in an extremely complex, and typically unpredictable ways. And, there's nothing you can do about it -- complex systems are going to fail, in the end. I don't actually subscribe to that point of view, because we have existence proofs that large, complex systems can be made to work. A good recent example is the Cassini Mission. I know John Cassani is down here on the floor. The Cassini Mission was an extremely complex, very expensive mission that ran for many years, continues to do well, and one of the great successes in large complex systems management. And, by the way, those who believe that large complex systems are bound to fail, will say also that the techniques and the methods that we use to prevent failure, to manage risk – thinks like redundancy failsafe operations, and those things, themselves, introduce more complexity, more risk, and therefore cancel out their intended effects, and maybe even make it worse.

So, I'll look at two different NASA management models: systems management, which sort of creeps on to the screen, and then faster, better, cheaper, which screened in from the left pretty fast. I've been involved in both, and I would imagine that most of you have.

Looking at Systems Management, I'll give you a definition for it. This is Johnson's definition – he says that systems management is a set of organizational structures and processes used to develop a novel, but dependable, technological artifact within a predictable budget. The two key words here are highlighted in kind of a green here, and that is dependable and predictable. One of the most important things about understanding the history and evolution of systems management is that it is really a system which was born of failure. That's really where it came from. It was a product of the Cold War, first and foremost. And, the reason that systems management began to evolve is because we were starting to do systems of unprecedented scale and complexity, and novelty. We were doing things like the hydrogen bomb, we were trying to do the ballistic missile program, and later on the Apollo program – and that environment was characterized by a strong national drive to develop and demonstrate technological superiority. That's really what a lot of it was about. And, so, in those times, in that geopolitical context, what was important was mission success. Cost wasn't actually all that big a deal. So, that's the reason why systems management was driven into existence. I think the reason why it was subsequently brought into widespread practice, and ultimately into acceptance, was because, as I said earlier, it was driven to that posture by failure.

And, by the way, a key point here, and I mentioned this earlier, cost wasn't that big a deal. Cost predictability was a very big deal. Uncertainty in cost, drove about a lot of the innovations in systems management – like configuration control, and other kinds of features. Schedule control, a lot of those techniques, came about because of cost unpredictability. The Congress, and the White House, could bear the cost of expensive systems. We were committed to it nationally; we were do things like Apollo, we were going to do things like the ballistic missile program, but the cost uncertainty drove them crazy. Which started in on something like Gemini, and the cost multiplied by a factor of five, or a factor of ten -- and that's what drove a lot of system management techniques into acceptance in this country.

Now, what are the characteristics of systems management? First and foremost, I think the most important, most valuable characteristic of systems management had to do with rigor. As I said, this was a failure driven kind of a evolution. In the '50s, when we were doing the Titan program and the ballistic missile program, about 50 percent of those missions were failures. We also lost, by the way, lost the first six Ranger missions--imaging missions to the moon--which were being managed out of JPL at that time. The Europeans spent a decade with their European launch development organization (this was mainly the British, and the French, and the Germans, and the Italians), they spent a decade trying to put together a launch vehicle without the benefit of systems management techniques. And, they blew up one rocket after another, and they actually never did succeed. In fact, one of the reasons they got interested in doing business with us in the '70s, with Spacelab, was because they wanted to learn systems management from the Americans.

So, if you look at rigor, the reason that rigor is a feature of systems management is because it's designed around trying to prevent failure. That's the reason you see things like environmental tests; rigorous environmental testing is a feature of systems management. Parts selections and control, documentation, interface management, quality inspections – all that stuff came out of the need to drive up reliability.

Predictability of cost and schedule was an important feature -- I mentioned this one earlier. This is where we get the origins of cost modeling. This is where we get the origins of configuration management. Configuration management was brought about to bring, not only technical discipline and understanding the configuration, but also to bring cost discipline to bear. It required people who were interested in making changes to the system to estimate the impacts technically on other systems, but also to try and understand and estimate the cost implications of those changes.

Bureaucracy is certainly a characteristic of systems management. In fact, Johnson called it an innovation of bureaucracy. It was really about trying to manage innovation, and trying to manage novelty in a systematic way, so you could better predict the outcome and have higher reliability. And, there were organizational innovations that came out of it, things like strong project control. Prior to the advent of systems management, research organizations were basically organized around the way universities had evolved, which is with departments with specialties. And, there was not a strong central project management feature. Systems management brought that to the fore.

Also, and interesting aspect of systems management was the transfer of risk from the private sector to the government sector. And, this really came about because of cost plus fixed-fee contracting. That was something that came up during World War II, because we were trying to develop complex systems quickly. We wanted to attract people like universities and the industrial component that would not otherwise be interested in doing business with the government. And, the way that was accomplished was to go to cost plus fixed-fee contracting, to ship the risk from the outside to the inside, and in the doing, invite more participation, and invite more innovation in the process. Of course, there was a price that you pay for it. When you go to cost plus fixed-fee contracts, you go to negotiated contracts, instead of arms-length commercial transactions, then you have to build up a government army to monitor all of that. Because, in doing the negotiated contracts, you have to understand thoroughly, all the elements of cost and price. And, when you have to do that, it means you have to have a smart buyer on the inside of the government – wearing the NASA badge in this case.

There's a meeting going on up in Houston, for the last couple of days, called the "Smart Buyer Conference". And, this is Ralph Roe, and a team from NESC, and what they are doing is, they're looking at how we should design and develop the CEV. And, the reason we're doing that, is so that we can inform the procurement process when it comes time to make a contractor selection. We've got people that are smart on the inside – and, that's really, again, a feature that comes from cost-plus fee contracting.

Another characteristic of systems management, in the end, is high cost. Now, as I said earlier, if you look at the geopolitical context here, you're looking at systems that came out of a Cold War context, that had to do with how we manage the strategic situation with our national prestige, and things like that. High cost was not really the issue. Again, cost predictability was an issue, but the absolute cost of the systems was actually not that serious a consideration. So, in other words, we were willing to accept high cost in exchange for high reliability and high predictability of cost.

I'll talk about faster, better, cheaper for just a minute. I got involved in faster, better, cheaper project a long time ago, within NASA, and it was a very interesting time for the agency. Faster, better, cheaper was championed, as you know, by the former administrator, Goldin. It was actually not invented within NASA, it was invented in the DoD world, and it was promoted for use within NASA for a lot of reasons. But, it was a management system based around the fundamental principle that you ought to be able to simultaneously approve schedule, and cost, and reliability -- or, schedule, and cost, and system performance – depending on how you think about it. Everybody's heard, famously heard "Faster, better, cheaper, pick any two" – that was sort of the joke that went around at the time. But, there are actually sort of interesting reasons to believe that the "pick any two", cynical as it is, is actually accurate. And, I've got some data to show you on that one.

There are really, two kind of fundamental ideas behind faster, better, cheaper, that drove the thinking on it. And, those two ideas were: to use smaller and lighter components, higher technology components, so that you could drive down launch weight, and it some cases, drive down complexity. So, you could certainly drive down in the end, cost, because you were having to throw less mass into orbit. And, then also, the idea that we ought to be able to manage more simply. To put in a phrase, “Substitute teamwork for paperwork”. That was the basic idea. Systems management evolved in such a way that were a lot of systems and a lot of bureaucracy that went with it. And I mentioned a lot of them, but looking at configuration management, looking at all the interface control documentation, all those kind of things that you did, those were all sort of heavily managed processes, with lots of documentation and lots of control, and for all the reasons that I’ve talked about. Because, we’re interested in driving up reliability, and driving down cost unpredictability.

Faster, better, cheaper was actually taking a different approach – it was saying “let’s drive down the cost of the system by using lighter weight things, and let’s drive down the cost of managing the system by replacing teamwork with paperwork.” Those are compelling ideas, but there’s also an interesting implication in all that. What we were saying at the time, was basically, we’re willing to trade some reliability for cost, for lowering the cost. And, so what you have here is, you’ve got a fundamental change in strategy, where you were dominated by a mission success mentality, and you actually went to be dominated by a cost-control mentality. I think it’s a very interesting thing. I think it’s also very interesting to look at it, again, in a geopolitical context. If you go back and you look at where you were with systems management; it was a Cold War oriented system. And, if you go look at faster, better, cheaper, that basically came out of the post-Cold War. It came out of the post-Cold War, and so the geopolitical context was different, and it actually drove us to a different systems management model, which said, “I’m more interested in constraining cost, and I’m less interested in mission success.” That was ultimately the bottom line of it. And, if you look at the failure reports from the Mars program, and Art Stephenson can probably talk about it today, that was the chief finding of that report, was that we got into a mentality where mission success was not the dominant feature in our thinking. It was more around cost control and other kinds of things, schedule management.

Now, what other guiding principles, in addition to cost containment were there? And there’s a lot to say about that. The project scale was kind of a principle. We do this on a fairly small scale, and there are reasons why you have to do that. Faster, better, cheaper does not work for systems that are of extremely high complexity, and I’ve got some data to demonstrate that too. It was about technical discretion, it was about putting more decision making into the hands of people who are working the project day to day.

Protection from red tape was a principle. Stable funding. Co-location was a very, very big deal. There are certain things that you have to do when you’re doing faster, better, cheaper. If you’re going to replace paperwork with teamwork, co-location was one of those things that you had to do. Because, if you’ve got people scattered all over the country, and you’re trying to do distributed decision-making, then sort of keeping the corporate knowledge of all of the decisions, all the interactions, and all the complexity, is much harder to do. And, we found that it was a contributing cause in some of the failures.

And, there are other features: hands-on work… rigorous testing was a principle in the very successful faster, better, cheaper. I think that Tony Spear's project, the Mars Pathfinder, really owes a lot of its success to the rigorous testing that went on in that program.

And, then risk taking… risk taking was a fundamental feature of faster, better, cheaper. Goldin used to say, he used to say, "If you're not failing, then you're not taking enough risk." Think about that in comparison to the systems management model and its view on mission success and risk. So, very different, very different point of view, driven by, in my opinion now, having looked at this, driven by geopolitical factors, chiefly.

Now, what is the track record for faster, better, cheaper? Well, there were about sixteen that were studied in McCurdy's book. And, I think this is about the sum total of them, because it really came to a screeching halt after the Mars Polar Lander, and the Mars Climate Observer. The successes were notable: Mars Pathfinder, Stardust, Lunar Prospector… In fact, nine out of the first ten faster, better, cheaper missions succeeded. There were notable failures: the Mars Climate Observer, the Polar Lander, Wire, Lewis and Clark, the latter – being just canceled, but still you would have to view it as a failure, and then Deep Space 2.

Now, what is it that when wrong? Now, this is a 63% success rate, and this compares with about a 90% success rate for systems management approaches. So, what is it that went wrong with faster, better, and cheaper? Well McCurdy's thesis is that two fundamental things went wrong. And, that is when management depresses the cost, or schedule, below the level that is required by mission complexity, then, basically what you do is you invite failure. In other words, reliability starts to compete with economy at a certain point. Reliability starts to compete with economy and that's a very important thing to understand in this process, and I'll show you a chart on that. And, the other thing that happened was that project managers, when they were replacing teamwork with paperwork, sometimes didn't go to the full lengths necessary to make that teamwork part of it really work – they weren't having daily stand-ups, or they weren't doing configuration management in some manner. If they weren't doing it formally, there were short cuts that were taken that really undermined the rigor that should have been necessary in faster, better, cheaper to make it work.

There's a third thing that I think went wrong -- this is a personal opinion. My personal opinion is that it was a failure from a policy point of view too. And, here's why: the public and the media did not distinguish a cheap failure from an expensive failure, really. If you have a spacecraft that crashes into the surface of Mars, if you have a spacecraft that burns up in the Martian atmosphere, or one that spins out of control, nobody cares. I mean, to them, it's just another expensive space mission; it's just another NASA failure. And, so I think from a policy point of view, if you're flying ten times as many missions you used to fly, and your failure rate is on the twenty to thirty percent threshold, then it's not tolerable. The agency cannot sustain that politically for a very long period of time. So, I think of a policy point of view, we really didn't understand that going into it. The idea that we're going to fly ten missions instead of one expensive flagship mission, and if seven or eight of those work, then we're in good shape – what that did fundamentally, was it sort of doubled, or tripled, or quintupled the failure rate of missions in the agency. And, that doesn't work in the end.

On the other hand, there is, there is a thing about faster, better, cheaper, that was sort of tantalizingly successful, in my opinion. If you look at the first sixteen missions, these sixteen missions were undertaken, the total cost of those missions was less than the cost of Cassini that I called out earlier. And, I don't say that to disparage Cassini; Cassini is a brilliant success for the agency. But, here you got ten successful missions that were doing interesting science, doing exotic things, and doing it on very low cost. And, so there's… sort of going back to the punch line of an old coarse joke that I'm not going to repeat, you've got to wonder if there's a pony in there somewhere. You know? And I think there is a pony in there, somewhere. And, I think the pony that's in there goes back to the fundamental principals behind faster, better, cheaper, which are the efficiency of the decision-making – and I think that's a lesson we ought to learn and apply to exploration. And, then also this idea of adapting technologies a little more aggressively, that could help you drive down weight, and help you drive down total system cost. I think we ought to take advantage of those features as much as we can in systems management, without sacrificing the rigor that's necessary for large complex systems.

Now, here's this chart that I referred to a couple… This is just remarkable, in my opinion, to look at this data. It came from David Bearden, from the Aerospace Corporation. I mentioned this one earlier, and this data results in the so-called Bearden Rules. And those rules are that schedule varies linearly with complexity – you can see that on the left-most chart over here – schedules varying, at least in a linear equation sense, with complexity. And, cost varies exponentially with complexity. And, complexity was a metric that was defined by Bearden and Sarsfield; Liam Sarsfield was involved in this study too. In terms of… They looked at things like the dry mass before launch, they looked at number of instruments, the pointing requirements, spacecraft control system and its complexity, propulsion techniques – the complexity of the propulsion system, things like that. And, they assigned complexity factors to those, and came up with these two sets of charts. And, I think it's just remarkable to look at. What's really remarkable about it is that these regions that are circled here, that are called the no-fly zones, and what the left-most chart suggests to you that schedule is compressible only to a certain point, and beyond that point you get a failure. So, management can crack the whip as much as they want to on schedule; there is a point at which you get breakage and you start to get mission failures. And, it's very consistent. It's not like there are two or three data points – they all failed below a certain threshold.

The other remarkable thing is that regardless of how much cost you allocate to a mission, in a faster, better, cheaper management model, there is only so much complexity you can accommodate with that model – regardless of how much cost you allocate to it.

Interesting also, that if you look at this – and I'm going back to the comment I made earlier about Perrow's thesis, that large complex systems are doomed to fail, this right-hand chart gives you a little support for that theory.

Now, get to my closing thoughts… I'll try to put a wrap on all this thinking. We've had in NASA's history, I think two dominant systems management themes, and those are: systems management itself, and faster, better, cheaper. What was kind of remarkable to me, in doing some thinking and working on this is, that those were very strongly driven by the geopolitical factors -- systems management by the Cold War, faster, better, cheaper by the post-Cold War mentality, which is not as concerned with things like mission success. And, I think that fundamentally we're kind of a tough… I think we're in a difficult spot from a project management model point of view, because the geopolitical factors and budgets don't really lend full support to a systems management mentality. In other words, we're not in the Cold War anymore. But, at the same time, as you embark on missions like returning to the moon, and going on to Mars, these are extremely complex systems; these are systems with high complexity and they demand a systems management approach. So, what are you going to do? I think it's a hard problem. I don't have a great answer to that. But, what I do think that you ought to try to do, as I said earlier, is incorporate the best features of faster, better, and cheaper into systems management. And, those features that I'm talking about again, have to do with decision efficiency and quality, and they have to do with adoption of technology to drive down complexity or mass, or whatever you can get with it.

And, how do you improve the decision quality and rate? My boss, Mike Griffin, says that project management is not a take home exam. And, I think that's a good way to put it. And, what he's saying there, is that you have to have competent people in project management, systems engineering leadership positions, who can make decisions on the spot, the ability to make decisions on the spot. So, technical leadership, decision efficiency is going to be extremely important as we go forward. And, I'm going to say something here that sounds like anathema, based on where we've been for the past ten years in the agency, but I don't believe that consensus and buy-in are the most important components of a decision. I believe that getting the right answer is the most important component of a decision; if you can get that other stuff, then you get some happiness with it and that's nice, but that's really what it's really about. We spend a lot of time in the agency, in my opinion, shopping decisions around, trying to get consensus, trying to build support. We don't need that, what we need is people that are capable of making decisions right the first time.

And, I think, by the way, technology can help here too, in the way of decision efficiency. We've got automation to unprecedented scales, we all carry around blackberries, we've got ways of collaborating electronically and otherwise. And, we ought to take full advantage of that to get better decision efficiency.

Now, I don't have any fresh thoughts on how we can adopt technology more quickly, more successfully, understanding what risk posture to take, and in doing so I'll leave that problem to the interested reader, and close with that thought.

Question: You mentioned Charles Purrow's "Normal Accident Theory". I have not really a question, I have comments. His theory is basically very controversial, and gave a picture of a very pessimistic view of large complex systems, and people feel like they are bound to have accidents. Actually, I think his theory provides very important implications on how we should… It's beyond that, the pessimistic view, but keep also a positive view on how we should learn from his theory and how we design the spaceware system. And, basically we can avoid designing a large complex system, and his theory basically says if it's a tightly coupled system, and high interactive complexity, it will give you a lot of accident scenarios. So, instead of designing large scale, more complex system, we should avoid using tightly coupled design, but we should decouple the system in directions, like a faster, better, cheaper. And, we should design… we have a tendency to design a system that's more complex, larger scale, and also more expensive. Not necessarily is that a good approach of system design.

Okay, thank you for that point. I agree with you entirely. And, I didn't make it well in this talk, but certainly driving down system complexity is a way to improve reliability and reduce cost. What concerns me is that as we go forward in exploration, and you start trying to do things like build Closed Loop Life Support, build spacecraft that can sustain humans on the way to Mars for eight or nine months, systems that will keep people alive on the surface, do in situ resource utilization and processing -- those things are just by definition, going to be highly complex systems. We do need to apply those techniques where we decouple systems from one another to the maximum extent, simplify as much as we can. But, we're stuck on a course of complex systems, and we've got to figure out how to manage them in the end. Thank you for the point. Well made.

Question: You talked about predictability of cost and schedule as being of paramount importance. I'd like you to talk a little bit about the reality of buying in – the fact that we probably… I know we wouldn't have gotten Space Station approved in the first place had we been honest with our estimated cost. I mean it came out to cost what we thought it was going to cost. It's a very dangerous political thing to do to go in kind of undercutting what you really know things are going to cost. And, I'd just like to hear your opinion from the hallowed halls of Washington.

Okay, thank you for the question. I don't think that buy-in has done us any favors over the years. NASA has gone through a crisis in credibility for probably two decades or better – for good reasons. Some of them have to do with mission success, but most of it having to do with cost creditability. So, I'm very high on putting together credible cost estimates. If it costs more than we can afford as a nation to do, then we shouldn't embark upon it. This subject has been discussed at the top-most levels of the agency. In fact, at our last strategic management council, we talked about how it is we cost estimate our missions, and how that relates to the budgeting for them. And, the decision that we got to was that we're going to use independent cost estimates with a certain confidence factor for the development of our budgets. And, we're going to require reconciliation between the independent cost estimates and the project cost estimates before we go forward and submit that into the budget. That's going to be a conservative posture, to be sure, compared to our history, but I also think it's going to put us on a better course for being able to do what we said we're going to do. And, there's too much on our plate, and we have to clear off a plate or two, then I think that's fine. I do believe that for exploration to get traction, and to go forward, it has to be cost credible. I just believe that to the bottom of my heart. And, so we're going to change our viewpoint on that. Buying in, in order to secure funding, when you know the cost isn't realistic, is doomed to failure—either programmatically or technically.